The evolution of mHealth interventions in Heart Failure

G.S. Karanasiou[1], E.E. Tripoliti[1], F.G. Kalatzis[1], A. Errachid[2], D.I. Fotiadis[1]

[1]Department of Biomedical Research, Institute of Molecular Biology and Biotechnology, FORTH, Ioannina, Greece.
[2]Université de Lyon, Institut de Sciences Analytiques (ISA), Lyon, France

Abstract—**Heart Failure (HF) is among the most deadly diseases globally with reduced quality of life (QoL), repeatable hospitalizations, and early mortality. For effectively managing HF patients should systematically monitor their symptoms and follow the experts' guidelines. While the precise mechanism behind HF disease has not been fully delineated, risk factors for HF have been identified. Though the risk factors are known, these is a compelling need for efficient and effective management and monitoring the progress of HF. Mobile health (mHealth) intervention has the potential to offer personalized services for predictive, participatory and preventative care and contribute to more accessible, faster and reliable disease monitoring. In this work we present an extended review of the evolution of mHealth interventions in cardiology and HF and the emerging potential these resources provide.**

Keywords— **Heart Failure, mHealth, personalized management, ecosystem, patient empowerment.**

I. Introduction

A. Background

HF is a life-threatening progressive disease associated with repeated hospitalizations and increased direct, such as medication and hospitalization, and indirect costs, such as income reduction [1]. Patients suffering from HF present several symptoms, such as sleep-disordered breathing [2] difficulty in breathing at rest or at exercise [3], urinary disorder [4], fast or irregular heartbeat [5], symptoms that have an adverse effect in patients Quality of Life (QoL).

The economic impact of the disease is enormous; high burden of hospitalizations as a primary or secondary diagnosis [6]. Life expectancy increases as well. As both the length of life and the proportion of older people increase throughout the world, the resources needed for HF care will further increase.

To decrease this economic pandemic, the risk factors related to HF should be effectively controlled. Among the available methods for assisting the HF patients in disease management are: (i) group consultations with a nurse or a healthcare professional [7], (ii) internet-based interventions [8], (iii) printed materials [9] and, (vi) mHealth applications [10]. From the aforementioned methods, the adoption of mHealth applications is the most promising [11].

B. Description of the condition

Current guidelines of the European Society of Cardiology (ESC) for HF management call for optimal management in hypertension, medication, nutrition, weight, physical activity. In parallel individualized education and counseling of HF self-care is a critical element [12]. The evolution in the field of medicine contributed to a widely available amount of medication for HF (Angiotensin-converting-enzyme inhibitor, Aldosterone Inhibitor, Angiotensin II Receptor Blocker, Beta-Blockers, Calcium Channel Blockers, Cholesterol -Lowering drugs, etc.). In specific HF stages, patients are more likely to be prescribed more than one kind of medication [13]. HF patients should also pay attention to the diet they follow and also include physical activity in their daily practice. Among other factors, weight monitoring is particularly important for HF patients and is highly associated with repeated hospitalization [14] and increased mortality [15]. According to clinical guidelines, weight monitoring is a key element in HF self-management [16], [17]. However, recent evidence reveal that only 40% of the HF patients are regularly monitoring their weight, and in addition a third of HF patients do not take any action [18].

However patients' non-adherence, in medication and in general in the provided by the experts' guidance, is "epidemic" [19]. This non-adherence behavior is a barrier to taking advantage of the existing knowledge and progress in medicine and has a negative impact in the patient's clinical condition, and consequently in his/her autonomy, physical and mental health and in general in QoL. Recognizing the non-adherent HF patients is important, since even though HF patients are fortunate to have at their disposal a plethora health-based knowledge, the adoption of this knowledge in their life is difficult.

Mobile technology has the potential to overcome barriers to monitor and manage HF patients and could be a useful tool for increasing patient adherence. Mobile health enhances access to health promotion interventions and can influence health related behavior in real-time [20]. A recent study revealed that 86% of the smartphone users are utilizing their smartphones to record, receive and review data, receive feedback and interact with other users [21]. Mobile usage, in Western Europe, was approximately 23% (2011) and its penetration is expected to expand, year after year,

reaching 65% (2017) [22]. In addition to this, even if older adults were less likely to utilize mobile technology, recent studies revealed an increase in mobile ownership and usage by them [23]. Mobile health interventions are adopted by a wide population with 20% of the mobile users downloading a mobile health application [24]. From the functional perspective, the mHealth applications can be classified in the following categories: (i) self-healthcare management (ii) assisted healthcare, (iii) supervised healthcare and (iv) continuous monitoring [25].

II. Methods

A. Literature review of mHealth HF interventions

Several studies have explored the feasibility of portable home-monitoring devices which are wirelessly connected to a smartphone with the aim to monitor HF patients [26], [27] and showed high diagnostic quality and integrity of vital measurements. A recent study monitored the patient's weight, through a wireless weight scale. The data were transmitted to a mobile phone, and with the help of an algorithm improved the sensitivity in predicting clinical deterioration in HF patients [28]. This was achieved through specific alerts which were generated from moving averages of daily weight data deviations above the norm for each patient.

The TEMA-HF 1 RCT included 160 HF patients from seven hospitals that utilized a telemonitoring system for communicating with the healthcare professionals and the HF clinic [29]. The patients were provided with sensors which measured daily weight, blood pressure (BP) and heart rate (HR) and when the predefined limits were exceeded, automatic alerts were generated. The evaluation of this telemonitoring system showed that the hospitalization rate was reduced.

Another telemonitoring systems with 50 HF patients determine its impact on: (i) self-care, (ii) clinical management and, (iii) health outcomes [30]. The quantitative findings revealed that the HF patients were empowered and the clinicians were able to more effectively manage these patients since patients' physiological data were at their disposal. A similar study showed that the mobile phone telemonitoring system improved patient's medication regimen [31]. Specifically, there was a significant increase in the patients that were prescribed with aldosterone antagonist, since they could be closely monitored. The benefits of aldosterone antagonist are well proven, however, patients are often not prescribed this therapy since in that case there is a need of closely monitoring serum potassium levels to avoid hyperkalemia. In addition to this, the HF patients were provided with immediate automated instructions to modify their lifestyle behavior.

The MOBITEL study [32], a prospective, randomized study with 120 patients from eight clinical centers, approached HF management through: (i) detecting early warning signs of decompensation, (ii) reducing the high risk of re-hospitalization and, (iii) through providing valuable patient information to the treating physician. The enrolled patients were equipped with: (i) a mobile phone, (ii) a weight scale and, (iii) a sphygmomanometer for BP and HR measurements. The measurements of the vital parameters were sent to the mHealth application on a daily basis. In addition, the perceived medication was inserted in the mobile application manually. Then all data were gathered and transmitted to a secure website where numerical and graphical data representation was provided. Through this system the physicians were able to monitor the patients' vital signs and receive an automatic alert in case the transmitted values were outside the personalized adjustable borders.

A study conducted by *Yap et al.* [33] included a chest-belt type two electrode wireless Electrocardiography (ECG) device and a specific mHealth application. Following the same concept, Leijdekkers *et al.* [34] presented a self-test mHealth application that allows HF patients to assess their medical condition and assist them in preventing heart attacks, without any medical expert's intervention. The basic concept is that the analysis of the ECG data are collected and analyzed and in case the patient is at risk there are mainly two choices: (i) the patient is informed and alerted to contact with the emergency services, (ii) the mHealth application automatically alerts the emergency services providing the location and the status of the patient.

Based on the findings of the previous studies, Seto et al. [31] generated a rule-based HF mHealth system. The patients were provided with wireless medical devices for measuring: (i) weight, (ii) BP, (iii) HR and, (iv) ECG. These data were transmitted to the mHealth application and then were sent to the hospital data servers for analysis. The objective of this system was to automatically generate alerts for the patients and the clinicians, through transforming the clinical guidelines in automated HF patient decision support and alerting systems. Findings showed that the utilization of the HF rule set improved patients' QoL and assisted in self-care.

There also exist mHealth applications that quantify vital signs. Such an application is the one that uses its camera and microphone to quantify HR and BP. In this mHealth application, two different approaches are used to estimate the vital signs from the heartbeat and pulse data. In the first approach, two smartphones are used whereas in the second approach the smartphone is replaced by an external microphone [35]. This mHealth application reached 95% accura-

cy in BP measurements. Another smartphone application of this kind is the iPhysioMeter that measures HR and normalized pulse volume (NPV) [36].

The objective of the HEARTEN is to build and evaluate a mHealth ecosystem for HF disease management [37]. A multidisciplinary HF management, involving several actors working together (healthcare professionals, caregivers, nutritionists, physical activity experts, psychologists), ensures patient adherence and best quality of disease progress. This is accomplished through several sensors and through the developed, within the project, breath and saliva biosensors. Specifically, the set of market sensors is: (i) ECG, (ii) BP, (iii) physical activity, (iv) body temperature and (v) weight scale. The breath and saliva biosensors will be integrated into the patients' smartphone and cup respectively. These biosensor devices will detect breath/saliva biomarkers that are indicative of HF progress and are linked with drug intake. The architecture of HEARTEN platform is depicted in Fig. 1.

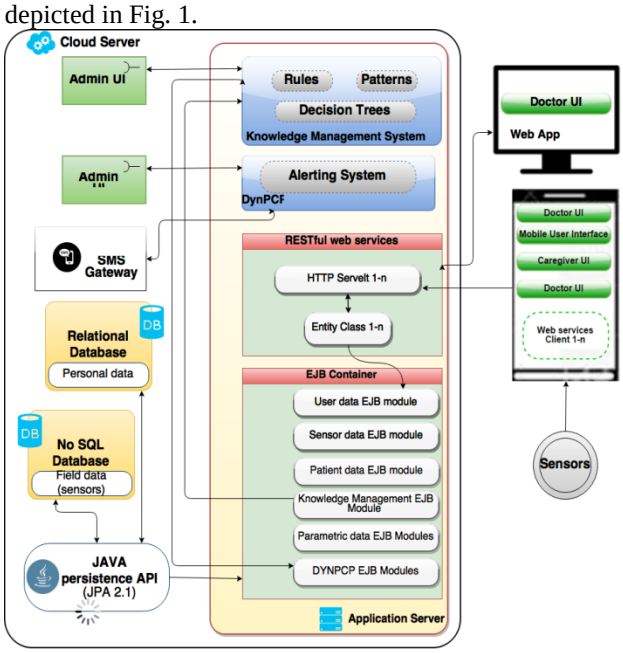

Fig. 1 Overview of HEARTEN architecture with the main components: (i) Sensors, (ii) Databases, (iii) KMS, (iv) DynPCP and, (v) Cloud Server.

All the measurements, from the sensors and the biosensors, will be gathered to the patient's mHealth application and then to HEARTEN Cloud platform where the Knowledge Management System (KMS) will employ data mining techniques for identifying: (i) high-risk conditions, (ii) patient's profiles, (iii) predictive models and, (iv) trends of non-adherence. Alerts and notifications will be send by the Dynamic Patient Communication Prototcol (DynPCP) system to the smartphones of the ecosystem actors and based on the authority of each of these actors specific recommendations and suggestions will be provided.

B. Review of commercial available mHealth HF interventions

In this section the most well-known mHealth applications are presented. A new mHealth application, SecuraFone® has been developed to provide immediate alerts to the healthcare professionals in case an unexpected health incidence occurs [38]. The patient wears a sensor on the chest or back that identifies and detects: (i) physical activity, (ii) HR, (iii) respiration rate and, (iv) skin temperature. Another iPhone case recently accepted by the U.S. Food and Drug Administration is AliveCor's Heart Monitor [39]. The AliveECG mHealth application records ECG and HR by resting it on the patient's fingers or chest.

A clinical trial called LAPTOP-HF was designed to assess a new methodology for managing HF patients [40]. A smartphone mHealth application, Pam+, allowed the HF patients to track the BP as measured by an implantable sensor [41]. The analysis of the processed data assisted in medication adjustment and resulted in maintaining blood pressure under acceptable levels.

III. Conclusions

The prevalence of mobile phones and the growing use of mobile-accessible applications in healthcare delivery highlight ways of integrating healthcare into the patient's daily routines bringing together and enabling ecosystem actors' interaction. The benefits of these interventions are clear, providing opportunities for direct and immediate HF patient management in a precise and effective way.

IV. Acknowledgment

This work is supported by the HEARTEN project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 643694.

References

[1] P. R. Pagley, G. A. Beller, D. D. Watson, L. W. Gimple, and M. Ragosta, "Improved Outcome After Coronary Bypass Surgery in Patients With Ischemic Cardiomyopathy and Residual Myocardial Viability," *Circulation*, vol. 96, no. 3, pp. 793–800, Aug. 1997.

[2] B. Sharma, D. McSharry, and A. Malhotra, "Sleep disordered breathing in patients with heart failure: pathophysiology and management," *Curr Treat Options Cardiovasc Med*, vol. 13, no. 6, pp. 506–516, Dec. 2011.

[3] B. Bozkurt and D. L. Mann, "Shortness of Breath," *Circulation*, vol. 108, no. 2, pp. e11–e13, Jul. 2003.

[4] C. Tannenbaum and K. Johnell, "Managing Therapeutic Competition in Patients with Heart Failure, Lower Urinary Tract Symptoms and Incontinence," *Drugs Aging*, vol. 31, no. 2, pp. 93–101, 2014.

[5] F. J. Pastor-Pérez, S. Manzano-Fernández, R. Goya-Esteban, D. A. Pascual-Figal, O. Barquero-Pérez, J. L. Rojo-Álvarez, M. D. M. Martinez-Espejo, M. V. Chavarri, and A. García-Alberola, "Comparison of Detection of Arrhythmias in Patients With Chronic Heart Failure Secondary to Non-Ischemic Versus Ischemic Cardiomyopathy by 1 Versus 7-Day Holter Monitoring," *The American Journal of Cardiology*, vol. 106, no. 5, pp. 677–681, 2010.

[6] S. Blecker, M. Paul, G. Taksler, G. Ogedegbe, and S. Katz, "Heart failure–associated hospitalizations in the United States," *J. Am. Coll. Cardiol.*, vol. 61, no. 12, pp. 1259–1267, Mar. 2013.

[7] D. E. Feldman, Y. Xiao, S. Bernatsky, J. Haggerty, K. Leffondré, P. Tousignant, Y. Roy, and M. Abrahamowicz, "Consultation with cardiologists for persons with new-onset chronic heart failure: A population-based study," *Can J Cardiol*, vol. 25, no. 12, pp. 690–694, Dec. 2009.

[8] R. P. Nolan, A. Y. Payne, H. Ross, M. White, B. D'Antono, S. Chan, S. I. Barr, F. Gwadry-Sridhar, A. Nigam, S. Perreault, M. Farkouh, M. McDonald, J. Goodman, S. Thomas, S. Zieroth, D. Isaac, P. Oh, M. Rajda, M. Chen, G. Eysenbach, S. Liu, and A. Zbib, "An Internet-Based Counseling Intervention With Email Reminders that Promotes Self-Care in Adults With Chronic Heart Failure: Randomized Controlled Trial Protocol," *JMIR Res Protoc*, vol. 3, no. 1, Jan. 2014.

[9] K. Taylor-Clarke, Q. Henry-Okafor, C. Murphy, M. Keyes, R. Rothman, A. Churchwell, G. A. Mensah, D. Sawyer, and U. K. A. Sampson, "Assessment of Commonly Available Educational Materials in Heart Failure Clinics," *J Cardiovasc Nurs*, vol. 27, no. 6, pp. 485–494, 2012.

[10] B. Martínez-Pérez, I. de la Torre-Díez, M. López-Coronado, and J. Herreros-González, "Mobile apps in cardiology: review," *JMIR Mhealth Uhealth*, vol. 1, no. 2, p. e15, 2013.

[11] T. Karhula, A.-L. Vuorinen, K. Rääpysjärvi, M. Pakanen, P. Itkonen, M. Tepponen, U.-M. Junno, T. Jokinen, M. van Gils, J. Lähteenmäki, K. Kohtamäki, and N. Saranummi, "Telemonitoring and Mobile Phone-Based Health Coaching Among Finnish Diabetic and Heart Disease Patients: Randomized Controlled Trial," *Journal of Medical Internet Research*, vol. 17, no. 6, p. e153, Jun. 2015.

[12] J. J. V. McMurray, S. Adamopoulos, S. D. Anker, A. Auricchio, M. Böhm, K. Dickstein, V. Falk, G. Filippatos, C. Fonseca, M. A. Gomez-Sanchez, T. Jaarsma, L. Køber, G. Y. H. Lip, A. P. Maggioni, A. Parkhomenko, B. M. Pieske, B. A. Popescu, P. K. Rønnevik, F. H. Rutten, J. Schwitter, P. Seferovic, J. Stepinska, P. T. Trindade, A. A. Voors, F. Zannad, A. Zeiher, and ESC Committee for Practice Guidelines, "ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure 2012: The Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure 2012 of the European Society of Cardiology. Developed in collaboration with the Heart Failure Association (HFA) of the ESC," *Eur. Heart J.*, vol. 33, no. 14, pp. 1787–1847, Jul. 2012.

[13] W. J. Paulus and J. J. M. van Ballegoij, "Treatment of Heart Failure With Normal Ejection Fraction: An Inconvenient Truth!," *Journal of the American College of Cardiology*, vol. 55, no. 6, pp. 526–537, 2010.

[14] S. I. Chaudhry, Y. Wang, J. Concato, T. M. Gill, and H. M. Krumholz, "Patterns of weight change preceding hospitalization for heart failure," *Circulation*, vol. 116, no. 14, pp. 1549–1554, Oct. 2007.

[15] M. Fiutowski, T. Waszyrowski, M. Krzemińska-Pakula, and J. D. Kasprzak, "Pulmonary edema prognostic score predicts in-hospital mortality risk in patients with acute cardiogenic pulmonary edema," *Heart Lung*, vol. 37, no. 1, pp. 46–53, Feb. 2008.

[16] H. Krum, M. V. Jelinek, S. Stewart, A. Sindone, J. J. Atherton, National Heart Foundation of Australia, and Cardiac Society of Australia and New Zealand, "2011 update to National Heart Foundation of Australia and Cardiac Society of Australia and New Zealand Guidelines for the prevention, detection and management of chronic heart failure in Australia, 2006," *Med. J. Aust.*, vol. 194, no. 8, pp. 405–409, Apr. 2011.

[17] C. W. Yancy, M. Jessup, B. Bozkurt, J. Butler, D. E. Casey, M. H. Drazner, G. C. Fonarow, S. A. Geraci, T. Horwich, J. L. Januzzi, M. R. Johnson, E. K. Kasper, W. C. Levy, F. A. Masoudi, P. E. McBride, J. J. V. McMurray, J. E. Mitchell, P. N. Peterson, B. Riegel, F. Sam, L. W. Stevenson, W. H. W. Tang, E. J. Tsai, B. L. Wilkoff, and American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, "2013 ACCF/AHA guideline for the management of heart failure: a report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines," *Circulation*, vol. 128, no. 16, pp. e240–327, Oct. 2013.

[18] M. H. L. van der Wal, T. Jaarsma, and D. J. van Veldhuisen, "Non-compliance in patients with heart failure; how can we manage it?," *Eur. J. Heart Fail.*, vol. 7, no. 1, pp. 5–17, Jan. 2005.

[19] A. A. Fitzgerald, J. D. Powers, P. M. Ho, T. M. Maddox, P. N. Peterson, L. A. Allen, F. A. Masoudi, D. J. Magid, and E. P. Havranek, "Impact of medication nonadherence on hospitalizations and mortality in heart failure," *J. Card. Fail.*, vol. 17, no. 8, pp. 664–669, Aug. 2011.

[20] W. T. Riley, D. E. Rivera, A. A. Atienza, W. Nilsen, S. M. Allison, and R. Mermelstein, "Health behavior models in the age of mobile interventions: are our theories up to the task?," *Transl Behav Med*, vol. 1, no. 1, pp. 53–71, Mar. 2011.

[21] "Just-in-time Information through Mobile Connections | Pew Research Center." http://www.pewinternet.org/2012/05/07/just-in-time-information-through-mobile-connections/.

[22] "Smartphone user penetration Western Europe 2011-2018 | Statistic,"*Statista*. http://www.statista.com/statistics/203722/smartphone-penetration-per-capita-in-western-europe-since-2000/.

[23] S. Fox and M. Duggan, "Mobile Health 2012," *Pew Research Center: Internet, Science & Tech*. .

[24] A. L. Beatty, Y. Fukuoka, and M. A. Whooley, "Using Mobile Technology for Cardiac Rehabilitation: A Review and Framework for Development and Evaluation," *J Am Heart Assoc*, vol. 2, no. 6, p. e000568, Dec. 2013.

[25] G. Chiarini, P. Ray, S. Akter, C. Masella, and A. Ganz, "mHealth Technologies for Chronic Diseases and Elders: A Systematic Review," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 9, pp. 6–18, Sep. 2013.

[26] D. Scherr, R. Zweiker, A. Kollmann, P. Kastner, G. Schreier, and F. M. Fruhwald, "Mobile phone-based surveillance of cardiac patients at home," *J Telemed Telecare*, vol. 12, no. 5, pp. 255–261, 2006.

[27] E. Piotrowicz, A. Jasionowska, M. Banaszak-Bednarczyk, J. Gwilkowska, and R. Piotrowicz, "ECG telemonitoring during home-based cardiac rehabilitation in heart failure patients," *J Telemed Telecare*, vol. 18, no. 4, pp. 193–197, Jun. 2012.

[28] M. T. Ledwidge, R. O'Hanlon, L. Lalor, B. Travers, N. Edwards, D. Kelly, V. Voon, and K. M. McDonald, "Can individualized weight monitoring using the HeartPhone algorithm improve sensitivity for clinical deterioration of heart failure?," *Eur. J. Heart Fail.*, vol. 15, no. 4, pp. 447–455, Apr. 2013.

[29] P. Dendale, G. De Keulenaer, P. Troisfontaines, C. Weytjens, W. Mullens, I. Elegeert, B. Ector, M. Houbrechts, K. Willekens, and D. Hansen, "Effect of a telemonitoring-facilitated collaboration between general practitioner and heart failure clinic on mortality and

rehospitalization rates in severe heart failure: the TEMA-HF 1 (TElemonitoring in the MAnagement of Heart Failure) study," *European Journal of Heart Failure*, vol. 14, no. 3, pp. 333–340, 2012.
[30] E. Seto, K. J. Leonard, J. A. Cafazzo, J. Barnsley, C. Masino, and H. J. Ross, "Perceptions and experiences of heart failure patients and clinicians on the use of mobile phone-based telemonitoring," *J. Med. Internet Res.*, vol. 14, no. 1, p. e25, 2012.
[31] E. Seto, K. J. Leonard, J. A. Cafazzo, J. Barnsley, C. Masino, and H. J. Ross, "Mobile Phone-Based Telemonitoring for Heart Failure Management: A Randomized Controlled Trial," *J Med Internet Res*, vol. 14, no. 1, Feb. 2012.
[32] D. Scherr, P. Kastner, A. Kollmann, A. Hallas, J. Auer, H. Krappinger, H. Schuchlenz, G. Stark, W. Grander, G. Jakl, G. Schreier, and F. M. Fruhwald, "Effect of Home-Based Telemonitoring Using Mobile Phone Technology on the Outcome of Heart Failure Patients After an Episode of Acute Decompensation: Randomized Controlled Trial," *J Med Internet Res*, vol. 11, no. 3, Aug. 2009.
[33] J. Yap, H. Yun, D.-U. Jeong, and Noh, "The Deployment of Novel Techniques for Mobile ECG Monitoring," *International Journal of Smart Home*, vol. 6, 2012.
[34] P. Leijdekkers and V. Gay, "A Self-Test to Detect a Heart Attack Using a Mobile Phone and Wearable Sensors," presented at the Conf Proc IEEE CBMS, 2008.
[35] V. Chandrasekaran, R. Dantu, S. Jonnada, S. Thiyagaraja, and K. P. Subbu, "Cuffless Differential Blood Pressure Estimation Using Smart Phones," *IEEE Transactions on Biomedical Engineering*, vol. 60, no. 4, pp. 1080–1089, Apr. 2013.
[36] K. Matsumura and T. Yamakoshi, "iPhysioMeter: a new approach for measuring heart rate and normalized pulse volume using only a smartphone," *Behav Res Methods*, vol. 45, no. 4, pp. 1272–1278, Dec. 2013.
[37] "HEARTEN: A co-operative mHealth environment targeting adherence and management of patients suffering from Heart Failure." [Online]. Available: http://www.hearten.eu/.
[38] "SecuraFone." http://www.securafone.com/subpages/health.php.
[39] "AliveCor-Home." http://www.alivecor.com/home.
[40] "LAPTOP-HF Trial |The University of Kansas Hospital | Kansas City, KS | The University of Kansas Hospital | Kansas City, KS." [Online]. Available: http://www.kumed.com/heart-care/clinical-services/heart-care-clinical-trials/laptop-hf.
[41] "Left Atrial Pressure Monitoring to Optimize HF Therapy Clinical Trials.gov." https://clinicaltrials.gov/ct2/show/NCT01121107.

Author: G.S. Karanasiou
Institute: Department of Biomedical Research,
Institute of Molecular Biology and Biotechnology, FORTH,
City: Ioannina
Country: Greece
Email: g.karanasiou@gmail.com